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Special issue on innovative methods and techniques for power and energy systems with high penetration of distributed energy resources

1. Background

The contemporary landscape of power and energy systems (P&ESs) is experiencing a significant transformation, marked by the integration of distributed energy resources (DERs) like solar photovoltaics, wind turbines, energy storage systems, and electric vehicles. Although these DERs bring forth myriad benefits, they also introduce challenges in variability management, uncertainty, and cyber vulnerabilities. This special issue of Energy Reports offers a comprehensive perspective on these intertwined challenges and opportunities.

Central to this issue are six pivotal domains: Energy Systems Planning and Coordination, Optimal Operation of Energy Systems, Cyber Security and Resilience of Power Systems, Renewable Energy/Energy Demand Forecasting and Control, Carbon Emissions and Environmental Factors in Energy Systems, and Stability and Control of Power Systems. The featured contributions address a broad spectrum of subjects, from power system stability and control and high-voltage direct current (HVDC) transmission systems to energy storage management and virtual energy storage systems. These articles present innovative strategies and solutions, meticulously designed to address the multifaceted challenges presented by DERs. Through their insights, they advocate for heightened resilience, operational efficiency, and environmental sustainability of P&ESs in the face of escalating complexities.

This background section showcases these pioneering advancements, highlighting their significant implications for the future direction of power and energy systems. With a commitment to spreading knowledge and nurturing collaboration, this issue acts as a guiding light in our collective stride towards a sustainable, resilient, and efficient energy future.

2. Energy systems planning and coordination

This topic underscores strategic planning's role in managing and integrating varied energy resources. It spotlights three studies, exploring multi-objective planning of electric vehicle charging stations, robust integrated energy systems (IES) planning, and coordinated urban multi-energy systems planning with inter-seasonal heat storage and power-to-gas (P2G) devices. These studies introduce unique models and methodologies, handling complexity and uncertainty in energy planning, fostering efficient and resilient energy operations.

In the realm of energy systems planning and coordination, a series of notable studies illustrate innovative strategies for optimizing and integrating diverse energy resources. Reference (Wang et al., 2022a) unveils an optimized model for EV charging station placement, balancing operator revenue and user charging costs, highlighting the role of urban traffic in these planning strategies. Further, reference (Fan et al., 2022) advances a robust planning model for Integrated Energy Systems, accounting for factors such as carbon trading and extreme scenarios, thereby underlining the strategic planning's potential to augment energy system resilience. Lastly, reference (Yu et al., 2023) investigates inter-seasonal heat storage and electric hydrogen production systems' role in urban energy networks, emphasizing the potential to boost renewable energy consumption and cut operational costs.

These studies demonstrate the essentiality of strategic planning and coordination for optimizing energy systems and integrating distributed energy resources. By utilizing innovative models and rigorous tests, they offer insights into factors affecting system performance, including urban traffic, extreme scenarios, and inter-seasonal variations. They underscore the necessity for ongoing research and innovation in energy systems planning as we progress towards a sustainable, resilient energy future.

3. Optimal operation of energy systems

This topic optimizes micro energy systems in various settings to improve energy efficiency, reduce carbon emissions, and lower costs. It incorporates flexible load management, demand response, and advanced optimization algorithms like particle swarm optimization. Innovative models are introduced for enhanced energy utilization and system performance.

The studies under review present a kaleidoscope of advancements in optimizing integrated energy systems. Reference (Wang et al., 2022a) illustrates the potential of a Stackelberg game-based model for enhancing operational flexibility in electro-thermal energy systems. Reference (Lin et al., 2022) explores an optimization model for micro energy systems that reduces costs and emissions while ensuring benefit distribution. Reference (Yang et al., 2022) introduces a two-stage optimization model improving isolated energy systems, while reference (Ju et al., 2022) highlights an approach to balance wind power, reducing costs through a Shapley-based mechanism. In an innovative shift, reference (Cui et al., 2023) applies machine learning to a Generalized Integrated Demand Response model, significantly reducing operating costs and CO_2 emissions. Reference (Meng et al., 2023) delves into multi-objective dispatch in demand response-enabled microgrids, whereas reference (Guo et al., 2023a) showcases a collaborative optimization for park energy systems that cuts costs and emissions. Finally, reference (Sun et al., 2023) optimizes energy management at the park level, reducing costs and peak power stress.

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The studies highlight the potential of integrated energy systems for energy conservation and carbon emission reduction. Advanced models and optimization techniques enhance energy utilization efficiency, increase renewable energy consumption, and minimize costs and emissions. Flexible load and demand response management are key factors in achieving these results. Further research and application of these methods can contribute significantly to global sustainable energy goals.

4. Cyber security and resilience of power systems

This topic delves into the realm of cyber security and resilience of power systems, addressing pivotal issues such as machine learning applications for safety hazard identification, hybrid data-driven strategies to bolster power system resilience against typhoon disasters, and proactive measures to mitigate false data injection attacks in power cyber-physical systems.

Through a critical review of current research, several noteworthy contributions emerge. Reference (Yang and Li, 2022) harnesses a hybrid data-model methodology, amalgamating wind field and system failure models with empirical typhoon scenario data to significantly enhance the resilience of power transmission systems against disasters, thereby shedding light on optimal resilience strategies. On another front, reference (Bo et al., 2022) delves into active defense strategies to combat false data injection attacks within power cyber-physical systems, providing a comprehensive analysis of six defense methods, elucidating their limitations, and paving the way for future multi-temporal defense strategies. Furthermore, reference (Qu et al., 2022) puts forth a knowledge-driven methodology for the identification and resolution of electrical safety hazards, leveraging advanced models like bidirectional encoder representation from transformers (BERT)-bidirectional long short-term memory (BiLSTM)-conditional random field (CRF) and ResPCNN-ATT to construct a knowledge graph and propose an intelligent reasoning model, the effectiveness of which is corroborated by practical hazard records.

Taken together, these studies significantly expand our understanding of and contribute valuable insights to the field of cyber security and resilience in power systems, encompassing diverse facets such as resilience against typhoon disruptions, defending against false data injection attacks, and the critical task of electrical safety hazard recognition. This research lays a strong foundation for future exploration and innovation in ensuring the robustness and security of our power systems.

5. Renewable energy/energy demand forecasting and control

This research collection on renewable energy/energy demand forecasting and control encompasses various methods and applications to enhance efficiency and reliability in renewable energy systems. It covers topics such as wind speed and photovoltaic power interval forecasting, multi-energy demand forecasting, control strategies for grid-connected wind turbines, the impact of load-photovoltaic (PV) profile resolution on distribution system risk assessment, control strategy of photovoltaic hydrogen generation systems, and control strategy of grid-connected hydrogen production units for weak grids.

In the field of renewable energy and energy demand forecasting and control, several references present innovative approaches. Firstly, reference (Meng et al., 2022) introduces a hybrid model for wind speed forecasting, demonstrating its effectiveness in short-term multi-step forecasting using Chinese wind farm data. Continuing, reference (Long et al., 2022) presents a high-accuracy hybrid deep learning model for wind speed prediction, showcasing superior accuracy, stability, and complexity. Additionally, reference (Wang et al., 2022a) proposes a forecasting method for day-ahead PV power that outperforms conventional models by utilizing clustering, deep convolutional generative adversarial networks, and quantile regression long short-term memory models to improve accuracy and quantify uncertainty. Furthermore, reference (Zhou and Cui, 2023) develops an adaptive method for cross-sector information identification to enhance multi-energy demand forecasting in regional integrated energy systems, achieving improved accuracy compared to benchmark models. Reference (Guo et al., 2023b) proposes a data-driven robust control strategy for low-frequency transmission wind turbines, meeting grid-connection requirements and ensuring frequency stability through real-time simulation experiments. Moreover, reference (Jia et al., 2023) utilizes super-resolution Generative Adversarial Networks to improve risk assessment accuracy by restoring high-frequency load-PV profile components. In addition, reference (Han et al., 2023) introduces a fuzzy proportional–integral (PI) control strategy for stabilizing PV hydrogen production systems, effectively reducing voltage and current ripple. Lastly, reference (Li et al., 2023) presents a Virtual Synchronization Generator control strategy for grid-connected hydrogen production units in weak grids, enhancing adaptability and promoting clean energy development.

The abovementioned studies in demonstrate advanced models and strategies for accurate forecasting and control. These include hybrid models and deep learning approaches for wind speed prediction, improved accuracy in PV power forecasting, and enhanced multi-energy demand forecasting. The proposed control strategies address stability and power regulation challenges in wind turbines, PV hydrogen production systems, and grid-connected hydrogen production units. These contributions optimize renewable energy systems and promote sustainable and clean energy solutions.

6. Carbon emissions and environmental factors in energy systems

This topic examines the relationship between carbon emissions, environmental factors, and energy systems. It covers diverse areas such as the feasibility of hybrid energy systems, optimization of carbon-free energy, improved carbon emission flow methods in power grids, and the adaptability of proton exchange membrane electrolysis in green hydrogen-electric coupling systems.

In the context of carbon emissions and environmental factors in energy systems, a range of studies offer valuable insights. Reference (Al-Ghussain et al., 2023) evaluates the feasibility of hybrid PV/wind systems with storage in Estonia, addressing electricity and thermal demands. It also explores the potential for surplus renewable energy utilization in district heating and green hydrogen production. Additionally, reference (Wang et al., 2022b) proposes a carbon-free energy optimization strategy for intelligent communities, incorporating renewable energy technologies and demand response. By leveraging power-to-hydrogen technology, this approach aims to reduce carbon emissions and energy costs. Furthermore, reference (Yang et al., 2023a) develops an improved carbon emission flow method for power grids involving prosumers, enabling quantification of carbon emissions from diverse sources. This method, tested on an IEEE 30-bus system, establishes a foundation for future research on carbon emissions. Lastly, reference (Dong et al., 2023) analyzes the adaptability of Proton Exchange Membrane Electrolysis (PEME) in a green hydrogen-electric coupling system, offering valuable insights for system operation and energy efficiency enhancements under various conditions.

These studies provide a comprehensive view of clean energy systems, efficient energy utilization, and innovative technology for carbon emission reduction. They emphasize the importance of renewable energy technologies, energy optimization, and proactive energy management strategies in reducing carbon footprints, facilitating the transition to a sustainable and carbon-neutral future. Further research should focus on exploring these avenues to maximize efficiency gains and environmental benefits.

7. Stability and control of power systems

This topic explores the stability and control of power systems, focusing on advanced control strategies, integration of renewable energy, and use of virtual energy storage. Key studies highlight the role of innovative control techniques, system partitioning, and optimal energy control in DC microgrids to improve both dynamic and steady-state stability, offering valuable insights for improving the robustness, resilience, and economic efficiency of modern power systems.

In the realm of power system stability and control, the studies at hand address various facets of dynamic control, system stability, and optimization. Firstly, reference (Li et al., 2022) develops a generic dynamic model to control inverter-based distributed generators during large disturbances. In a similar vein, reference (Wang et al., 2023a) investigates multi-time-scale control interactions in grid-forming converters and identifies destabilizing factors. Meanwhile, reference (Fu et al., 2022) enhances DC microgrid stability and economics by using an optimized control method for active loads. Building upon this, reference (Yang et al., 2023b) expedites hybrid power grid restoration through a novel partitioning method using multiple line commutated converter-based HVDC (LCC-HVDC) systems. Additionally, references (Wang et al., 2023b; Zhang et al., 2023a) explore control strategies for DC microgrids and energy storage systems respectively, both yielding significant benefits in operational efficiency and system stability. Reference (Wang et al., 2023c) takes a step further by implementing an adaptive linear active disturbance rejection control for HVDC systems, leading to improved response speed and disturbance stability. Finally, reference (Zhang et al., 2023b) presents a novel voltage stability assessment for new energy power systems, offering valuable insights into voltage security for renewable energy systems.

This topic emphasizes the importance of advanced control strategies and modeling for enhancing power system stability amid the growth of renewable and distributed resources. These innovative approaches, focusing on energy storage and system partitioning, ensure the robustness, resilience, and economic efficiency of modern power systems, signposting the future of grid integration and operation.

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Declaration of Competing Interest

None.

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